Towards Cost-Effective Provisioning and Survivability in Ultra High Speed Networks

Bin Wang
Department of Computer Science and Engineering
Wright State University
Dayton, OH 45435

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Outline

- Project Description
  - Focus
  - Personnel
  - Summary of Accomplishments
  - Publications
- Description of Accomplishments
  - Scheduled Traffic Model
  - Service Provisioning
  - Survivability Provisioning
- Future Work

Project Focus

- Target the need of supporting DOE science mission
- Study the scheduled traffic model and its variations, and service provisioning, bandwidth scheduling, collaboration scheduling, as well as QoS provisioning under this traffic model to support bandwidth on-demand
- Enhance the network's ability to survive network faults by providing cost-effective survivability with a fast recovery speed and a variety of survivability options

Personnel

- PI: B. Wang
- Students: Tianjian Li, Xubin Luo, Yuqi Fan
- Collaborators: ORNL, UltraNet

Summary of Accomplishments

- Sliding scheduled traffic model
- Time conflict reduction algorithm
- Support unicast under the scheduled traffic model
- Support multicast under the scheduled traffic model
- Traffic grooming: multi-resolution unicast channels
- *Shared path based and p*-cycle based protection for translucent networks

Publications

- Cost-Effective Shared Path Protection in WDM Optical Mesh Networks with Partial Wavelength Conversion, with Tianjian Li. Accepted for publication in *Photonic Network Communications,* 2004.
- Efficient Online Algorithms for Dynamic Shared Path Protection in Optical WDM Networks, with Tianjian Li. Accepted for publication to *Photonic Network Communications* 2004.
- Efficient Traffic Grooming in SONET/WDM BLSR Networks, with Abdur Billah, and Abdul A. S. Awwal. *Optical Engineering Journal*, Vol. 43, No. 5, pp. 1101-1114, May 2004
- Traffic Grooming under a Sliding Scheduled Traffic Model in WDM Optical Networks, with Tianjian Li, Xubin Luo, and Yuqi Fan. Proceedings of IEEE Workshop on Traffic Grooming in WDM Networks, San Jose, CA USA, October 29, 2004.
- Optimal Configuration of *p*-Cycles in WDM Optical Networks with Sparse Wavelength Conversion, with Tianjian Li. Proceedings of *IEEE Globecom'04*, Dallas, TX USA, November/December 2004.
- Dynamic Multicast Session Provisioning in WDM Optical Networks with Sparse Splitting Capability. *7th INFORMS Telecommunications Conference*, Boca Raton, FL March 2004.

Traffic Models

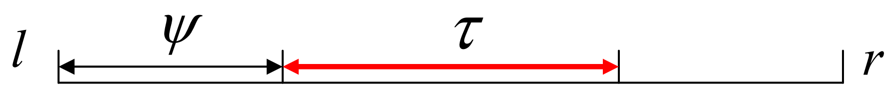
- Following traffic models in open literature:
  - static traffic model
    - all demands are known in advance and do not change over time
  - dynamic random traffic model
    - a demand is assumed to arrive at a random time and last for a random amount of time
  - admissible set traffic model
    - demands are from some prescribed traffic matrices
  - incremental traffic model
    - demands arrive sequentially. Lightpaths are established for each demand, and the lightpaths remain in the network traffic indefinitely

DOE Science Applications

- Many US DOE large-scale science applications must deliver Gbps throughput *at scheduled time*
- *These applications require provisioning of scheduled dedicated channels or bandwidth pipes at a specific time with certain duration*
- These scheduled capacity demands are dynamic
  - demands only last during the specified intervals
  - they are not entirely random

Proposed Sliding Scheduled Traffic Model

- A demand (*s*, *d*, *n*, *ℓ*, *r*, τ)



- *s*: source
- *d*: destination (or a destination set)
- *n*: capacity requirement
- τ: duration, or lasting time
- [*ℓ*, *r*]: time window during which demand of duration τ and with a capacity requirement of *n* must be satisfied
- Example: (*s*, *d*, 1, 10:00, 13:00, 60 minutes)

Time Conflict & Resource Conflicts

- Time conflicts of a set of scheduled demands *M* (temporal conflicts)
  - Demands may overlap in time →different resources needed
  - Demands that are disjoint in time allow resource reuse

- Resource conflicts (spatial conflicts)
  - Routes of demands may overlap
  - If not enough resources are available on shared routes, conflicts result
  - Some demands may not be schedulable because of lack of resources

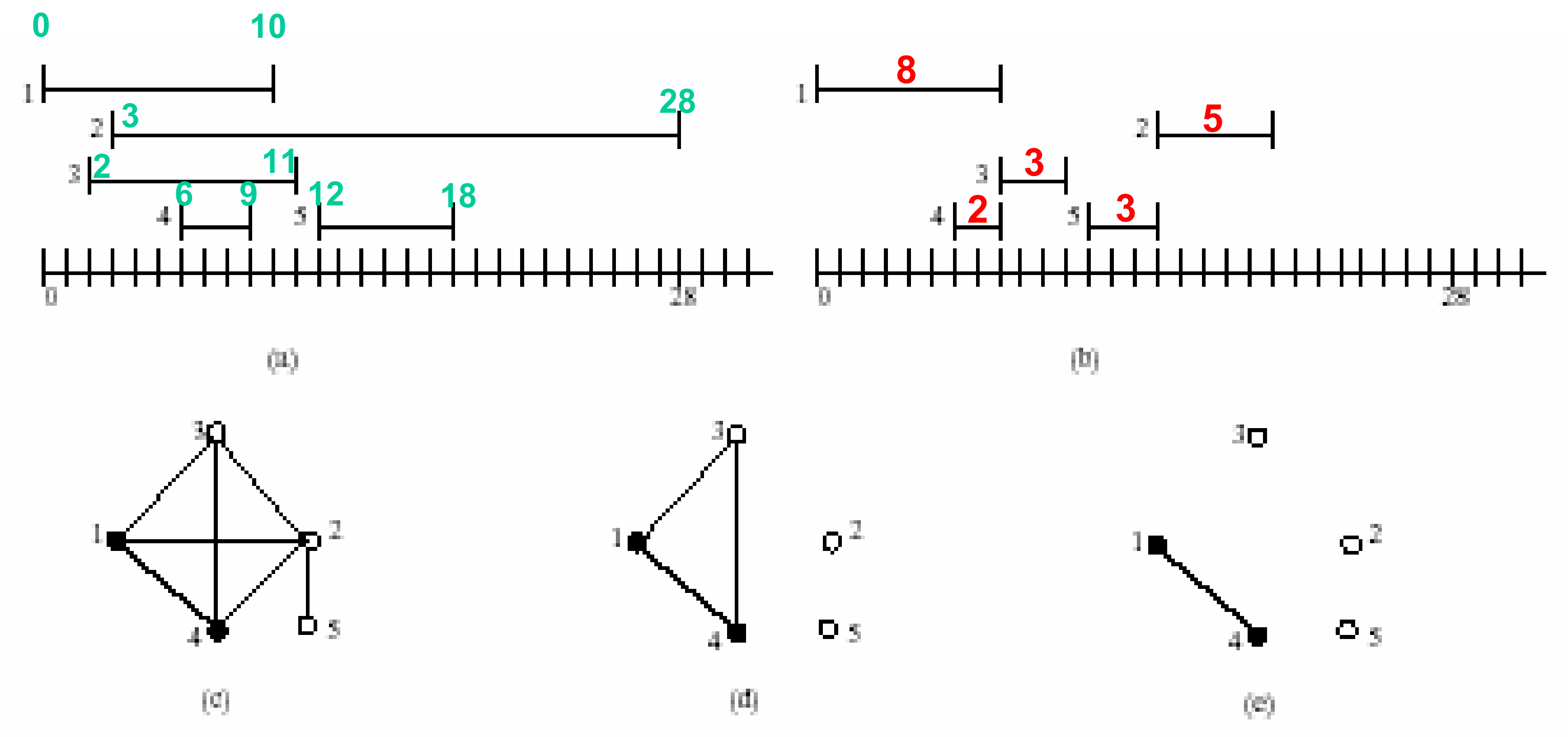
R&D Issues

- Scheduling algorithms for supporting *unicast* as well as *multicast* communications
- Schemes for providing and scheduling on-demand reconfigurable logical networks
- Mechanisms for supporting dedicated channels and *multi-resolution* channels – traffic grooming
- Mechanisms for supporting multicast with multi-resolution bandwidth requirements
- Derive schedulability conditions and performance bounds under the scheduled traffic model
  - elementary network topology: link, ring, star, tree
  - general networks

R&D Issues

- QoS provisioning for delay/jitter agile applications
- Designing integrated schemes that are capable of supporting different services or integration of different schemes under a unified framework
- Protection/survivability strategies under the scheduled traffic model

Time Conflict Reduction



Time Conflict Reduction Algorithm

- Use an interval graph to model time conflicts among scheduled demands
- Identify time conflicts that may be avoided
- Remove time conflicts in a greedy manner to obtain proper placement of demand intervals within their allowed time windows

Space-Time Scheduling Problem

- Given a set of sliding scheduled traffic demands *M* properly placed within their time windows, the problem is to *route* and *assign a proper wavelength* to each demand in *M* such that

  - the ***non-blocking case***

  - the network has enough resources to accommodate all the demands in *M* to meet their specifications (i.e., capacity and schedule requirements)

  - the goal is to minimize total network resources used

Space-Time Scheduling Problem

- the ***blocking case***

- the network does not have enough resources to accommodate all the demands as specified
- the goal is
  - to minimize the number of demands to be *rearranged* (i.e., to minimize the subset of demands that may have their starting time changed: postponed or proponed) in order to have all the demands in the set *M* accommodated by the network

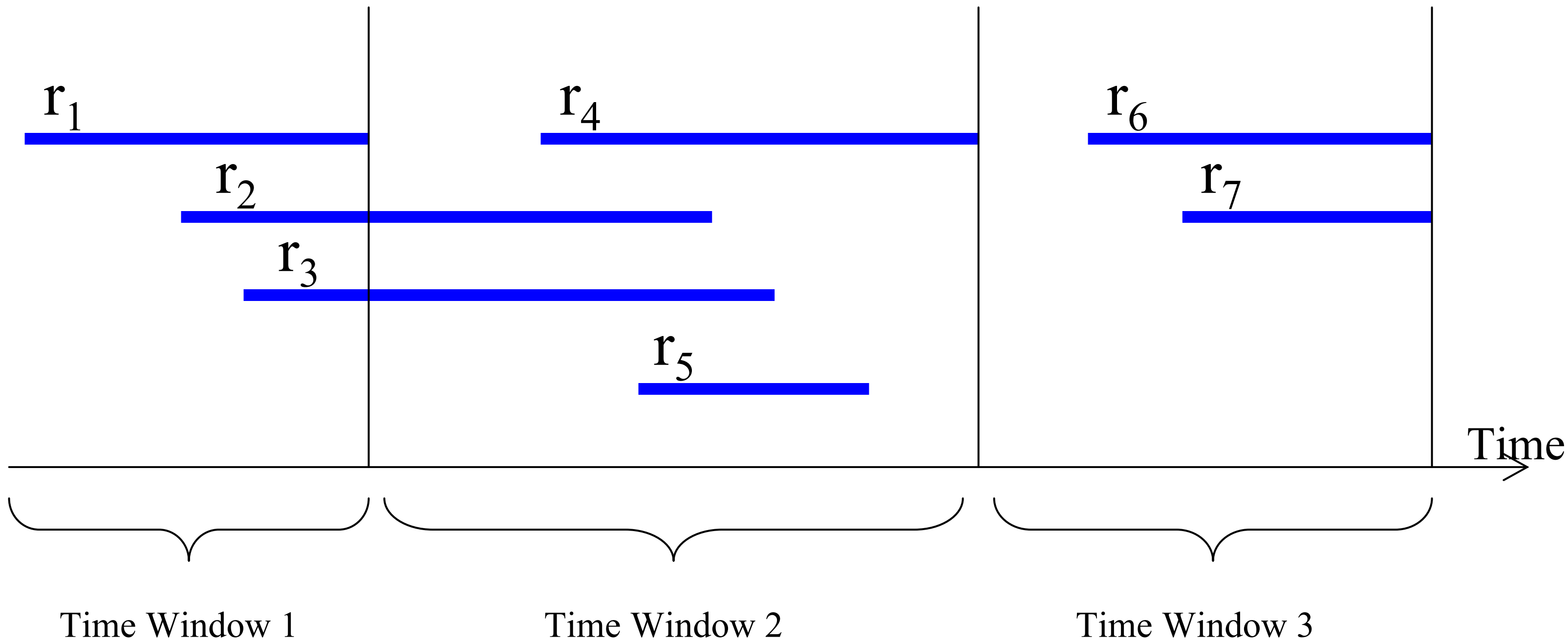
  - to minimize of total network resources used

- *This problem can be shown to be NP-complete*

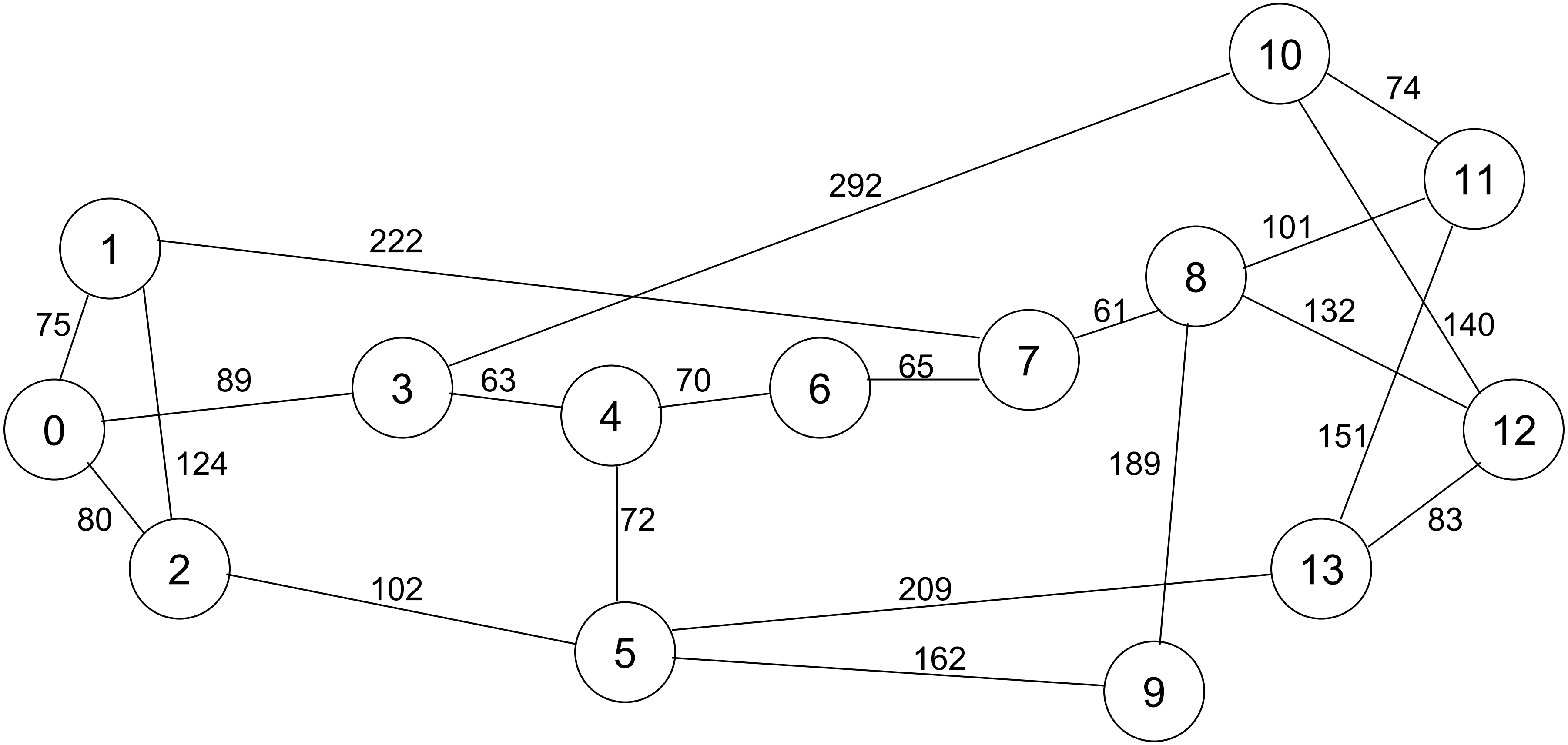
Time Window Based Scheduling Algorithm For Supporting Unicast

- Divide a set of scheduled demands into subsets called *time windows*
- Demands in a time window have time conflicts pair wise
- Schedule demands in a time window according to demands' decreasing resource requirements
  - Using a modified Dijkstra's algorithm on a layered graph
- If a demand is blocked due to unavailability of resources, *rearrange* the schedule of the demand
  - Schedule the demand *earlier or later in time* when the required resources are available

Demand Set Division



NSFNET



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162
9

- Time correlation of a demand set
  - characterize the extent of conflicts among demands in the time domain
  - weak, medium, strong
- Demand sets contain 50-400 scheduled bidirectional demands
  - Amount of capacity uniformly from [1,9]
- 30 wavelengths per link
- Comparison of two algorithms: TWA and TMA, also results from tabu search

Preliminary Results - I

- *The percentage of demands rearranged* is very small under weak and medium demand time correlation scenarios – almost zero using TWA algorithm
  - Effective in meeting demand specifications

- Percentage of rearranged demands increase as # of demands and time correlation increase

Preliminary Results - II

- TWA performs better than TMA
- *Total wavelength-links* used by TWA is smaller than that of TMA when time correlation is weak and medium
  - TMA performs slightly better when time correlation is strong
- TWA outperforms TMA in terms of *max number of wavelengths on a link*
  - Which increases with increasing # of demands and stronger time correlation

Preliminary Results - III

- Time correlation has a significant impact on the cost of a solution

- Both algorithms try to minimize the total number of wavelength-link used *by letting rearranged demands reuse* the wavelength-links that have been used by scheduled demands that are time disjoint

Preliminary Results - IV

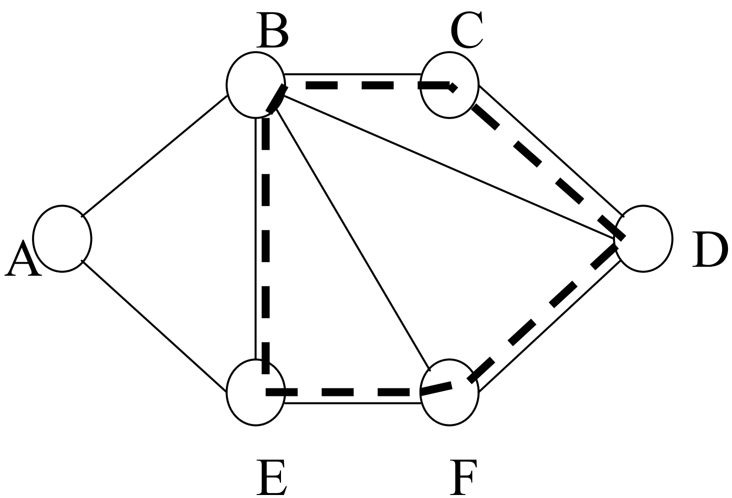
- Compared with tabu search based optimization
- Results of TWA algorithm are very close to those of tabu search in terms of # of wavelength-links used (when time correlation is weak or medium)
- Tabu search performs slightly better when time correlation is weak and # of alternate paths used by tabu search is large
- TWA outperforms tabu search when time correlation is strong
  - Since our customized tabu search uses fixed alternate routing
- TWA much more computationally efficient

Extension

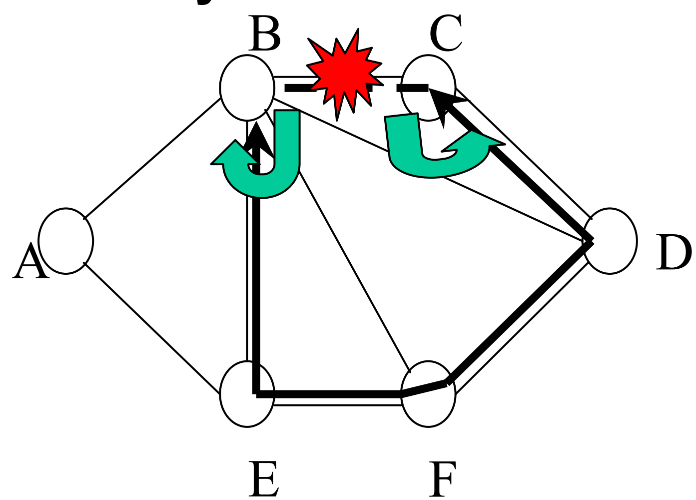
- We have extended and are in the process of evaluating and refining our scheduling algorithms to
  - Support multicast
  - Support multi-resolution unicast channels
  - Wavelength convertible networks

Pre-configured Cycle (*p*-cycle)

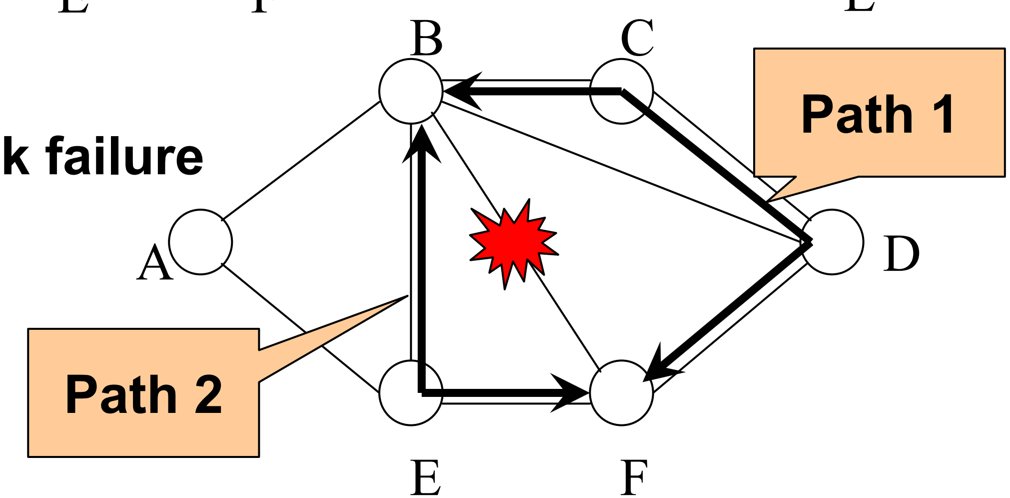
A *p*-cycle in a network



On cycle link failure

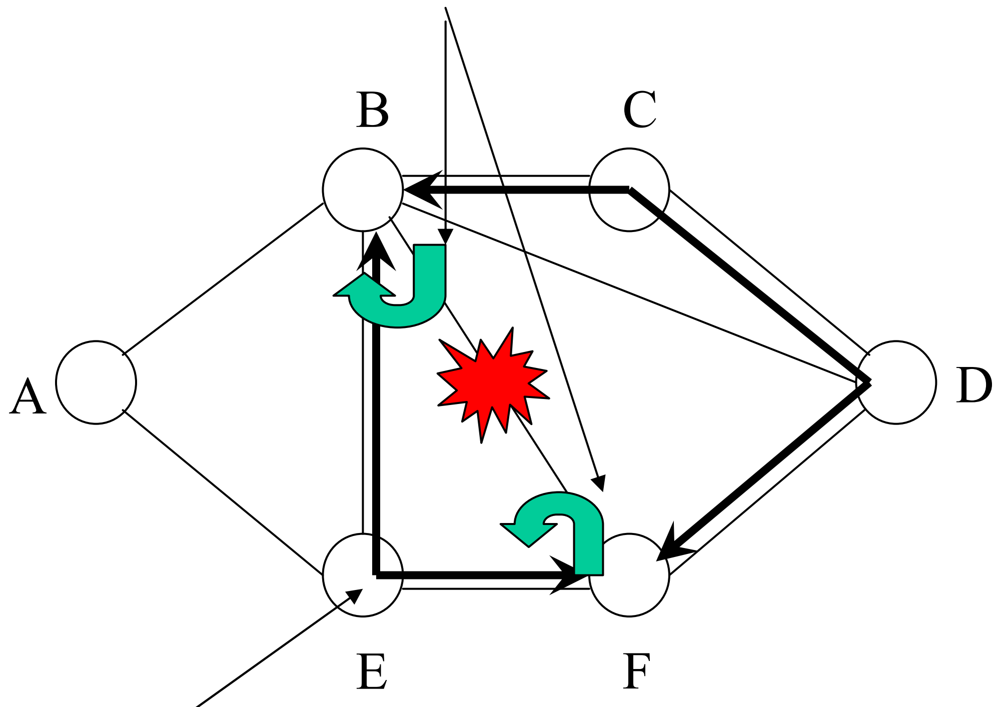


Straddling link failure



Protection Switching and Inter-node Signaling

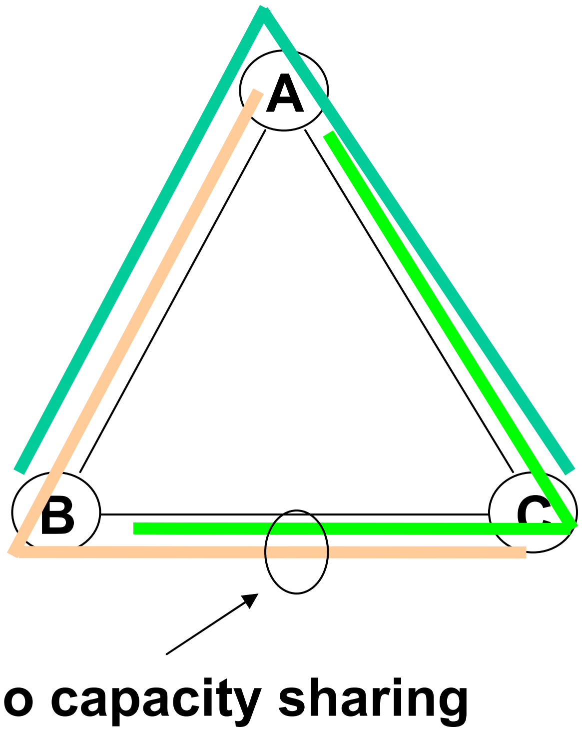
Nodes neighboring the failure react



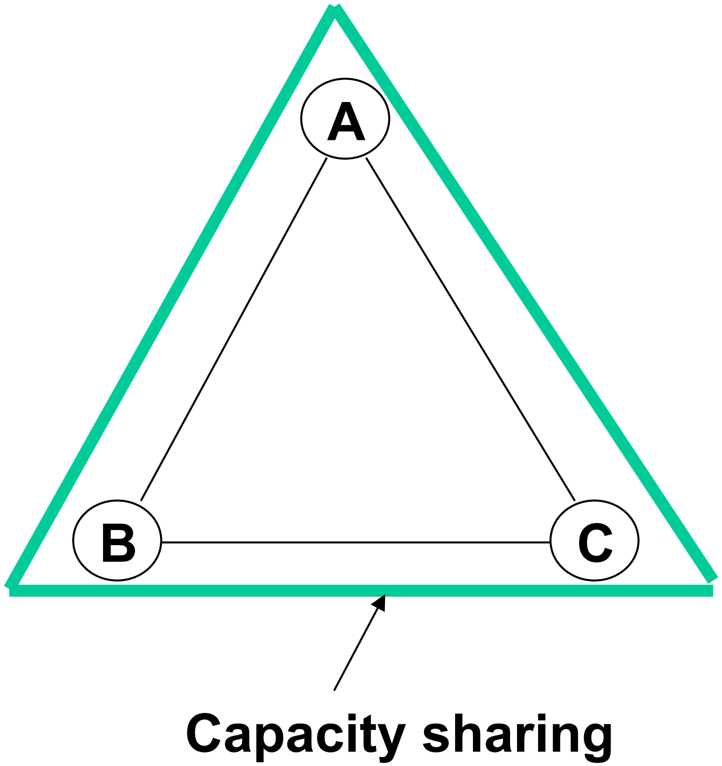
No protection path signaling needed (Preconfiguration) ⇒ **Fast protection switching**

Link Protection vs. *p*-cycles in WDM Networks

- Link protection (dedicated, without inter-node signaling):



- *p*-cycles:



p-cycle Based Protection

- A pre-configured cycle (*p*-cycle) based protection technique combines the benefits of both
  - the traditional ring-based and
  - path-based approaches

  - it can achieve *ring-like recovery speed* while retaining the desired *capacity efficiency of path-based protection* approaches.

R&D Issues

- Protection for surviving single network faults in translucent networks
  - the most common case
- Protection for surviving double network faults in translucent networks
  - which are also quite likely, e.g., faults occur before a fault gets repaired
  - for applications that require extreme survivability
- Mechanisms for providing grade of protection depending on service or application requirements to offer options (with different associated costs) for protection if necessary

p-cycle Based Protection for Translucent Networks

- We consider translucent networks
- We consider the general case in which a *p*-cycle is allowed to use wavelength conversion partially on the path (translucent)
- Take full advantage of converter sharing
  - (a) when converters are used for accessing *p*-cycles and for wavelength conversion between two adjacent on-cycle spans;
  - (b) when converters are used by disjoint straddling spans incident to the same node for accessing *p*-cycles
  - to reduce costs by requiring as few converters as possible

p-cycle Based Protection for Translucent Networks

- Deployment of *p*-cycles:
  - Multiple cycles in a large network
  - Fixed cycle infrastructure
  - *p*-cycles configured by network management system
- Routing and *p*-cycle configuration
  - Joint optimization (ILP)
    - Working demand and protection capacity considered jointly
  - Two-step approach (ILP)

p-cycle Configuration: Preliminary Results - I

- NSFNET and a smaller network (for joint optimization)
- Total cost includes: wavelength-link and conversion

- Our two-step approach incurs much less cost than the other two approaches in terms of total cost
- Our joint optimization approach outperforms other approaches in terms of total cost
- Our approaches use fewer total number of converters
- Our approaches use fewer max number of converters at a node

Future Work

- Refine traffic model
  - Consider split interval traffic model
  - Demand is given as a number of non-intersecting time segments
  - Other practical models
- Future R&D issues
- Some of the algorithms and mechanisms proposed will be implemented and tested on the test-bed network in collaboration with DOE UltraNet
- Develop methods and APIs for connection set-up, scheduling, reservation, and allocation

Future R&D Issues

- Support dynamic scheduled traffic demands
- Taking application non-deterministic data readiness into account in the scheduling algorithms
- Refine scheduling algorithms for supporting *unicast* as well as *multicast* communications
- Schemes for providing and scheduling on-demand reconfigurable logical networks
- Refine mechanisms for supporting dedicated channels and *multi-resolution* channels
- Mechanisms for supporting multicast with multi-resolution bandwidth requirements

Future R&D Issues

- Derive schedulability conditions and performance bounds under the scheduled traffic model
- QoS provisioning for delay/jitter agile applications
- Designing integrated schemes that are capable of supporting different services or integration of different schemes under a unified framework
- Protection/survivability strategies under the scheduled traffic model

Future R&D Issues

- *Shared path based protection*
- *p*-cycle based protection for surviving single network faults in translucent networks
- *p*-cycle based protection for surviving double network faults in translucent networks for applications that require extreme survivability
- Protection of sub-wavelength circuits with traffic grooming
- Mechanisms for providing grade of protection depending on service or application requirements to offer options (with different associated costs) for protection if necessary